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# NACA

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# RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

SUPPLEMENTARY INVESTIGATION IN THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL OF A 1/20-SCALE MODEL OF THE DOUGLAS F4D-1 AIRPLANE WITH EXTERNAL WING FUEL TANKS

TED NO. NACA AD 3116


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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

DEC 27 1957

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## INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, a supplementary investigation has been made in the Langley 20-foot free-spinning tunnel on a 1/20-scale model to determine the spin and recovery characteristics of the Douglas F4D-1 airplane equipped with external fuel tanks. Previous spin tests conducted on a model of the XF4D-1 airplane without fuel tanks installed are presented in references 1 and 2.

Model spin tests were conducted with the external fuel tanks installed for both erect and inverted spins for the normal loading condition with the center of gravity located at 24 percent mean aerodynamic chord. One-third-full and two-thirds-full fuel tanks were simulated. Brief tests were also made to determine the parachute size required for satisfactory recovery with fuel tanks installed.

## SYMBOLS

| | |
|---|---|
| $b$ | wing span, ft |
| $S$ | wing area, sq ft |
| $\bar{c}$ | mean aerodynamic chord, ft |
| $x/\bar{c}$ | ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord |
| $z/\bar{c}$ | ratio of distance between center of gravity and fuselage reference line to mean aerodynamic chord (positive when center of gravity is below line) |
| $m$ | mass of airplane, slugs |
| $I_X,I_Y,I_Z$ | moments of inertia about X, Y, and Z body axes, respectively, slug-ft$^2$ |
| $\frac{I_X - I_Y}{mb^2}$ | inertia yawing-moment parameter |
| $\frac{I_Y - I_Z}{mb^2}$ | inertia rolling-moment parameter |
| $\frac{I_Z - I_X}{mb^2}$ | inertia pitching-moment parameter |

[redacted]

$\rho$ air density, slugs/cu ft

$\mu$ relative density of airplane, $m/\rho Sb$

$\alpha$ angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

$\phi$ angle between span axis and horizontal, deg

V full-scale true rate of descent, ft/sec

$\Omega$ full-scale angular velocity about spin axis, rps

## APPARATUS, METHODS, AND PRECISION

An available 1/20-scale model of the Douglas XF4D-1 airplane used for previous investigations (refs. 1 and 2) was employed for the present investigation. A three-view drawing of the model as tested with fuel tanks installed to simulate the F4D-1 is shown in figure 1. The dimensional characteristics of the F4D-1 airplane are essentially the same as those of the XF4D-1 (ref. 1) except that the trimmers on the F4D-1 are slightly larger and the rudder is slightly smaller than on the XF4D-1. The rudder for the F4D-1 airplane is constructed in two parts: an upper rudder which is servo-operated and a lower rudder which is manually operated. The upper servo-operated rudder has an area of about one-half that of the lower manually operated rudder. The model used in this investigation was not modified to incorporate these changes since they were small and would be expected to have little or no effect on the spin and recovery characteristics of the model. For the model tests of this investigation, the complete rudder was deflected. The trimmers were deflected for some of the tests.

The lateral and longitudinal controls are combined into one pair of control surfaces called elevons. Longitudinal control was obtained by deflection of both elevons in the same direction and lateral control was obtained by deflection of the elevons differentially. However, in this report, elevon deflection for longitudinal and lateral control is referred to, for simplicity, as elevator and aileron deflections, respectively.

The mass characteristics and inertia parameters for the normal loading condition with wing tanks for the F4D-1 airplane and for the loading tested on the model are presented in table I. The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 15,000 feet ($\rho$ = 0.001496 slug/cu ft).

The XF4D-1 maximum control deflections differ slightly from those for the F4D-1. A line diagram showing limitations on the maximum deflections of the elevons on the airplane (simultaneous movement of the ailerons and elevators to maximum deflection) is shown in figure 2. The maximum control deflections (perpendicular to the hinge lines) for the F4D-1 airplane and the deflections used on the model are as follows:

| | |
|---|---|
| Rudder, deg | 30 right, 30 left |
| Elevators, deg | 20 up, 10 down |
| Ailerons, deg | 20 up, 20 down |
| Trimmers, deg | 30 up, neutral |

Results determined in free-spinning tunnel tests are believed to be true values given by models within the following limits:

| | |
|---|---|
| $\alpha$, deg | ±1 |
| $\phi$, deg | ±1 |
| V, percent | ±5 |
| $\Omega$, percent | ±2 |
| Turns for recovery obtained from motion-picture records | $\pm\frac{1}{4}$ |
| Turns for recovery obtained visually | $\pm\frac{1}{2}$ |

The preceding limits may be exceeded for certain spins in which it is difficult to control the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

The accuracy of measuring the weight and mass distribution of models is believed to be within the following limits:

| | |
|---|---|
| Weight, percent | ±1 |
| Center-of-gravity location, percent $\bar{c}$ | ±1 |
| Moments of inertia, percent | ±5 |

Controls are set with an accuracy of ±1°.

Because it is impracticable to ballast models exactly and because models are inadvertently damaged during tests, the measured weight and mass distribution of the F4D-1 model varied from the true scaled-down values as follows:

| | |
|---|---|
| Weight, percent | 1.5 low |
| Center-of-gravity location, percent $\bar{c}$ | $\frac{1}{2}$ to 1 rearward |

Moments of inertia:
$I_X$, percent . . . . . . . . . . . . . . . . . . . . . . . . . 1 low
$I_Y$, percent . . . . . . . . . . . . . . . . . . . . . . . . . 1 high
$I_Z$, percent . . . . . . . . . . . . . . . . . . . . . . . . . 1 high

The model testing technique is the same as that presented in reference 1.

## RESULTS AND DISCUSSION

Model spin test results are presented in charts 1 to 3 for erect spins and in charts 4 and 5 for inverted spins. The parachute test results are presented in table II. All results were similar for the right and left spins and are arbitrarily presented in terms of right spins.

### Erect Spins

The spins obtained for all loadings were slightly oscillatory and recoveries were satisfactory when a control technique of reversing the rudder to full against the spin was accompanied by simultaneous movement of the ailerons to full with the spin. The deflection of the trimmers had little or no effect on the spin or recovery characteristics. Model results indicated that after recovery it may be possible to enter a spin in the opposite direction. It is recommended, therefore, that all controls be neutralized immediately after recovery. The installation of the tanks does not alter the recovery technique previously recommended for the airplane in reference 1.

Model results also indicated that, for the airplane, the tendency to obtain a developed spin would be increased and that recoveries, although still satisfactory, would be slightly slower when tanks were nearly full than when they were nearly empty or off. These effects, based on spin-tunnel experience with this and other models, appeared to be primarily due to mass-distribution effects rather than to aerodynamic effects.

### Inverted Spins

The order used for presenting the data for inverted spins shows controls crossed for the established spin (right rudder pedal forward and stick to pilot's left for a spin to pilot's right) at the right of the chart and stick back at the bottom. When controls are crossed in the established spin, the ailerons aid the rolling motion; when the controls are together, the ailerons oppose the rolling motion. For inverted spins, the directions up and down for elevator deflection and angles of wing tilt $\phi$ presented on the charts are given with respect to the ground.

For satisfactory recovery from inverted spins with tanks installed, model results indicated that movement of the rudder to at least neutral would be necessary and that neutralization of all controls would be desirable for recovery. This technique is in agreement with the recovery technique obtained from previous tests of reference 2.

### Parachute Results

The parachute test results (table II) indicated that a 14.2-foot-diameter (laid out flat) parachute with a drag coefficient of 0.71 (based on the laid-out-flat diameter) and a towline length of 33.3 feet will be adequate for satisfactory recoveries in an emergency when tanks are installed. This parachute is essentially the same as that recommended in reference 1, except that the towline length has been increased. If a parachute with a different drag coefficient is used, a corresponding adjustment is required in the diameter of the parachute. The parachute towline was attached to the arresting hook to simulate the installation on the airplane.

## SUMMARY OF RESULTS

Based on results of spin tests of a 1/20-scale model, the following conclusions regarding the developed spin and recovery characteristics of the Douglas F4D-1 airplane with external wing fuel tanks installed at an altitude of 15,000 feet are made:

1. Satisfactory recovery will be obtained from erect spins by rudder reversal accompanied by movement of ailerons to full with the spin (stick right in a right spin). To avoid entering another spin, all controls should be neutralized immediately upon recovery.

2. The tendency to spin will be greater and recoveries will be somewhat slower when tanks are nearly full than when they were almost empty or off.

3. For satisfactory recovery from an inverted spin, movement of the rudder to at least neutral will be necessary and neutralization of all controls will be desirable.

4. For satisfactory recovery in an emergency, a parachute 14.2 feet (laid out flat) in diameter with a drag coefficient of 0.71 (based on the laid-out-flat diameter) and a towline length of 33.3 feet will be adequate.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 9, 1957.

## REFERENCES

1. Lee, Henry A.: Free-Spinning and Tumbling Characteristics of a $\frac{1}{20}$-Scale Model of the Douglas XF4D-1 Airplane As Determined in the Langley 20-Foot Free-Spinning Tunnel - TED No. NACA DE 346. NACA RM SL50K30a, Bur. Aero., 1950.

2. Klinar, Walter J., and Lee, Henry A.: Supplementary Investigation in the Langley Free-Spinning Tunnel of a 1/20-Scale Model of the Douglas XF4D-1 Airplane Including Spin-Recovery Parachute Tests of the Model Loaded to Simulate the Douglas F5D-1 Airplane - TED No. NACA AD 3116. NACA RM SL55L02, Bur. Aero., 1955.

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TABLE I.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR THE LOADINGS OF THE DOUGLAS F4D-1 AIRPLANES AND FOR THE LOADINGS TESTED ON THE 1/20-SCALE MODEL

[Values given are full-scale, and moments of inertia are given about the center of gravity]

| Model loading number | Condition | Weight, lb | Center-of-gravity location | | Relative density, $\mu$ | | Moments of inertia, slug-feet$^2$ | | | Mass parameters | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $x/\bar{c}$ | $z/\bar{c}$ | Sea level | Altitude, 15,000 ft | $I_X$ | $I_Y$ | $I_Z$ | $\frac{I_X - I_Y}{mb^2}$ | $\frac{I_Y - I_Z}{mb^2}$ | $\frac{I_Z - I_X}{mb^2}$ |
| Airplane values | | | | | | | | | | | | |
| 1 | Design flight | 18,215 | .24 | --- | 12.76 | 20.28 | 12,425 | 37,679 | 48,403 | $-398 \times 10^{-4}$ | $-169 \times 10^{-4}$ | $567 \times 10^{-4}$ |
| 2 | Design flight with two 300-gal. external tanks empty | 18,613 | .24 | --- | 13.03 | 20.70 | 13,237 | 37,813 | 49,153 | -379 | -175 | 554 |
| 3 | Design flight with two 300-gal. external tanks 1/3 full | 19,915 | .24 | --- | 13.94 | 22.14 | 15,877 | 38,157 | 51,499 | -321 | -192 | 513 |
| 4 | Design flight with two 300-gal. external tanks 2/3 full | 21,215 | .24 | --- | 14.85 | 23.57 | 18,517 | 38,433 | 53,775 | -269 | -207 | 476 |
| 5 | Design flight with two 300-gal. external tanks full | 22,515 | .24 | --- | 15.75 | 25.04 | 21,186 | 39,583 | 56,928 | -234 | -221 | 455 |
| Model values | | | | | | | | | | | | |
| 3 | Design flight with two 300-gal. external tanks 1/3 full | 19,573 | .24 | 0.008 | 13.69 | 21.79 | 15,852 | 38,503 | 52,015 | $-332 \times 10^{-4}$ | $-198 \times 10^{-4}$ | $530 \times 10^{-4}$ |
| 4 | Design flight with two 300-gal. external tanks 2/3 full | 20,877 | .25 | .017 | 14.59 | 23.23 | 18,346 | 38,657 | 54,323 | -279 | -215 | 494 |

[redacted]

TABLE II.- SPIN-RECOVERY TAIL-PARACHUTE DATA OBTAINED WITH THE

1/20-SCALE MODEL OF THE DOUGLAS F4D-1 AIRPLANE

[Model loading 4 on table I; recovery attempted by opening tail parachute; ailerons maintained at full (15°) against the spin, elevator maintained full up, and rudder maintained full with the spin, right erect spins. Model values converted to corresponding full-scale values.]

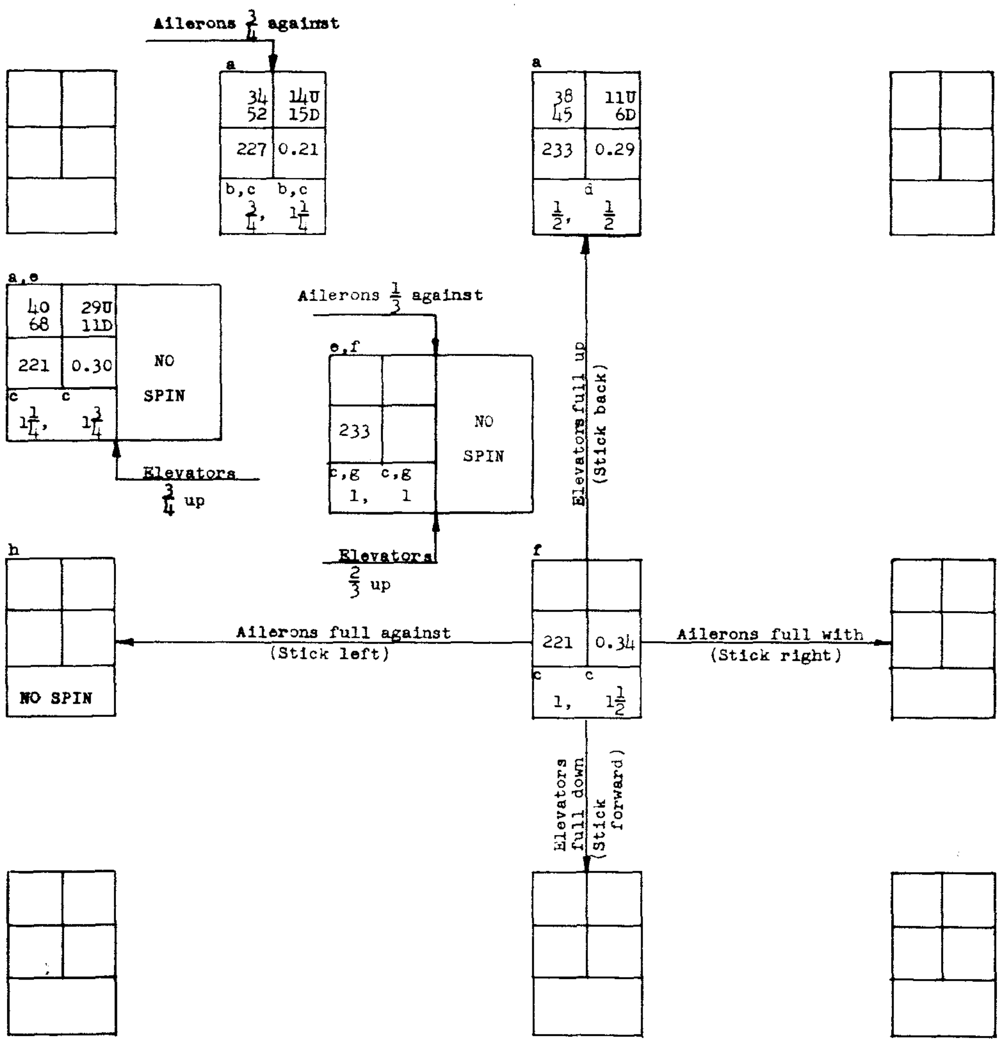
| Parachute diameter, ft | Towline length, ft | Parachute drag coefficient | Turns for recovery |
|---|---|---|---|
| 14.2 | 33.3 | 0.71 | 1, 1, $1\frac{1}{4}$, $1\frac{1}{4}$, $1\frac{1}{2}$ |

CHART 1.–SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by simultaneous rudder reversal to full against the spin and movement of ailerons to full with the spin unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Spin direction simulated | Loading (see table I) No. 3 | |
|---|---|---|---|---|
| F4D-1 | Erect | Right | Design-flight configuration with two external fuel tanks 1/3 full | |
| Slats | Altitude | Trimmers | Desired center-of-gravity position | |
| | 15,000 ft | 0° | 24 percent $\bar{c}$ | |

Model values converted to full scale U-inner wing up D-inner wing down




[a]Oscillatory spin, range or average values given.
[b]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full (15°) with the spin.
[c]Model recovered in a dive.
[d]After recovery, model started spinning in opposite direction.
[e]Two conditions possible.
[f]A very oscillatory spin.
[g]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to 2/3 (of 20°) with the spin.
[h]Model rolled inverted, then entered a dive.

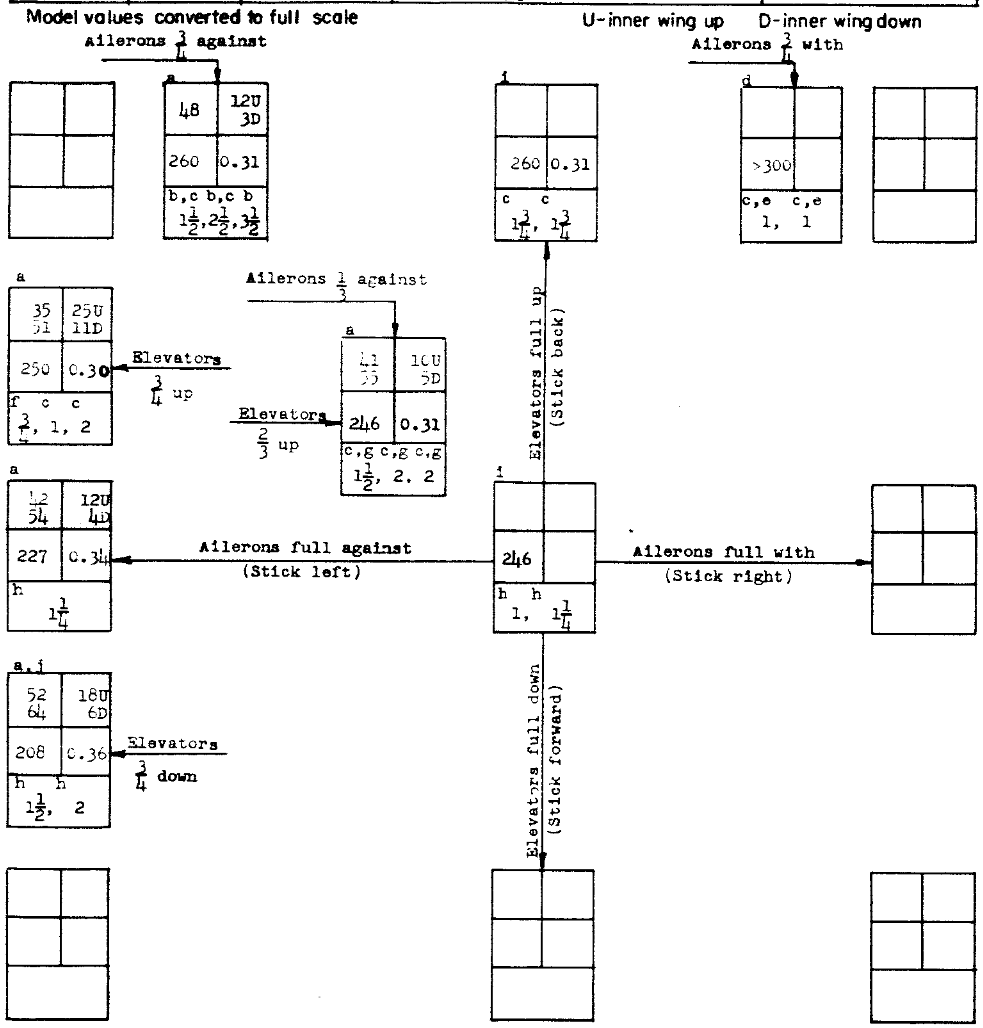
| | |
|---|---|
| α (deg) | φ (deg) |
| V (fps) | Ω (rps) |
| Turns for recovery | |

[redacted]

CHART 2.—SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by simultaneous rudder reversal to full against the spin and movement of ailerons to full with the spin unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Spin direction simulated | Loading (see table I) No. 4 | |
|---|---|---|---|---|
| F4D-1 | Erect | Right | Design-flight configuration with two external fuel tanks 2/3 full | |
| Slats | Altitude | Trimmers | Desired center-of-gravity position | |
| | 15,000 ft | 0° | 24 percent c̄ | |




[a]Oscillatory spin, range or average values given.
[b]Recovery attempted by simultaneous reversal of rudder to full against the spin and movement of ailerons to full (15°) with the spin.
[c]Model recovered in a dive.
[d]Very steep spin, recovery attempted before model reached final attitude.
[e]Recovery attempted by reversal of rudder to full against the spin.
[f]Model recovered in an inverted dive.
[g]Recovery attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to 2/3 (of 20°) with the spin.
[h]Model recovered in a rolling dive.
[i]Steep and wandering spin.
[j]Very wandering spin.

| | |
|---|---|
| $\alpha$ (deg) | $\phi$ (deg) |
| V (fps) | $\Omega$ (rps) |
| Turns for recovery | |

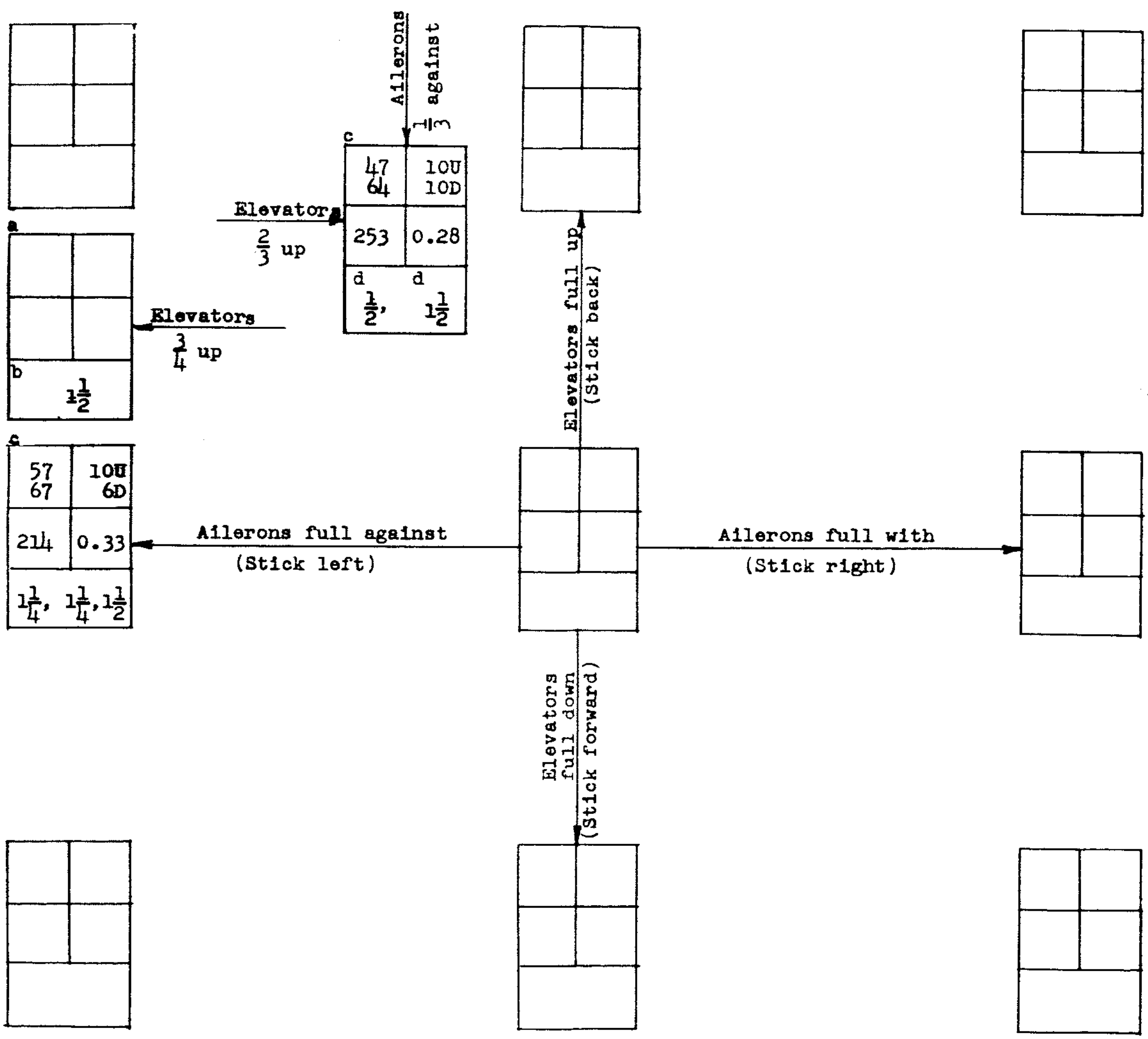
[redacted]

CHART 3 .–SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted by simultaneous rudder reversal to full against the spin and movement of ailerons to full with the spin unless otherwise noted (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Spin direction simulated | Loading (see table I) No. 4 | |
|---|---|---|---|---|
| F4D-1 | Erect | Right | Design flight configuration with two external fuel tanks 2/3 full | |
| Slats | Altitude | Trimmers | Desired center-of-gravity position | |
| | 15,000 ft | $-30^{\circ}$ | 24 percent $\bar{c}$ | |

Model values converted to full scale U-inner wing up D-inner wing down




[a] A very wandering and oscillatory spin.
[b] Model recovered in a dive, then turned in opposite direction.
[c] Oscillatory spin, range of values given.
[d] Recoveries attempted by simultaneous reversal of rudder to 2/3 against the spin and movement of ailerons to 2/3 (of 20°) with the spin.

| | |
|---|---|
| $\alpha$ (deg) | $\phi$ (deg) |
| V (fps) | $\Omega$ (rps) |
| Turns for recovery | |

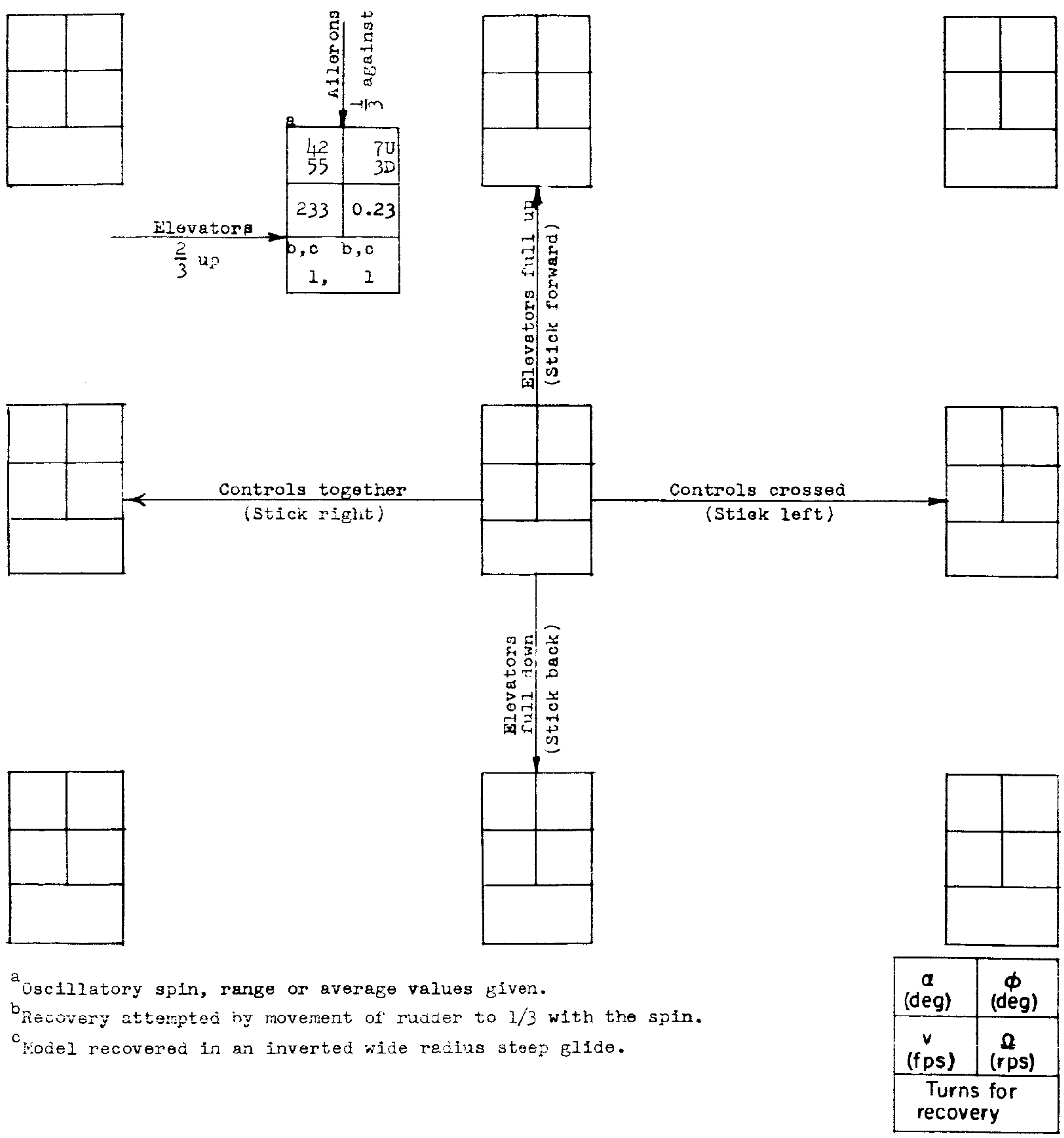
[redacted]

CHART 4.-SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted as indicated (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Spin direction simulated | Loading (see table I) No. 3 |
|---|---|---|---|
| F4D-1 | Inverted | Pilot's right | Design-flight configuration with two external fuel tanks 1/3 full |
| Slats | Altitude | Trimmers | Desired center-of-gravity position |
| | 15,000 ft | 0° | 24 percent $\bar{c}$ |

Model values converted to full scale U-inner wing up D-inner wing down




[a]Oscillatory spin, range or average values given.
[b]Recovery attempted by movement of rudder to 1/3 with the spin.
[c]Model recovered in an inverted wide radius steep glide.

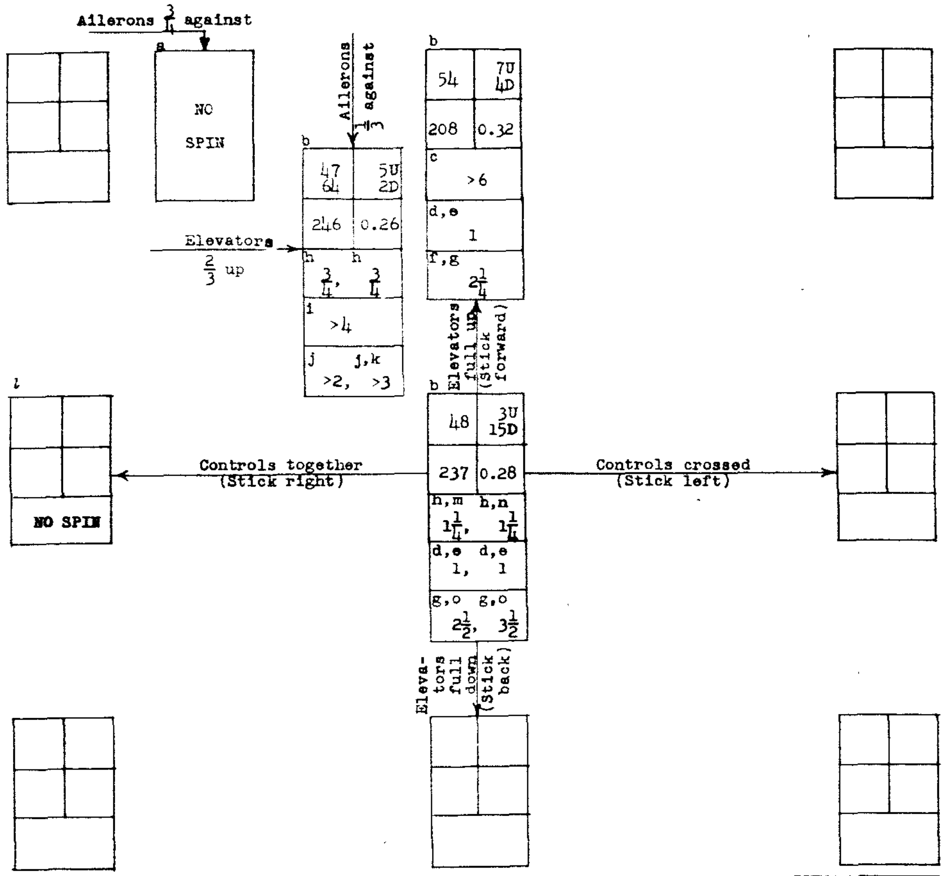
[redacted]

CHART 5.-SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Recovery attempted as indicated (recovery attempted from, and developed-spin data presented for, rudder-full-with spins)]

| Airplane | Attitude | Spin direction simulated | Loading (see table I) No. 4 | |
|---|---|---|---|---|
| F4D-1 | Inverted | Pilot's right | Design-flight configuration with two external fuel tanks 2/3 full | |
| Slats | Altitude | Trimmers | Desired center-of-gravity position | |
| | 15,000 ft | 0° | 24 percent $\bar{c}$ | |

Model values converted to full scale U-inner wing up D-inner wing down




| $\alpha$ (deg) | $\phi$ (deg) |
|---|---|
| v (fps) | $\Omega$ (rps) |
| Turns for recovery | |

[a] Model entered an inverted dive.
[b] Oscillatory spin, range or average values given.
[c] Recovery attempted by movement of rudder 10° with the spin.
[d] Recovery attempted by movement of rudder 10° against the spin.
[e] Model recovered in an erect dive.
[f] Recovery attempted by simultaneous movement of rudder to 10° with the spin and movement of ailerons to full (15°) with the spin.
[g] Model recovered in an aileron roll.
[h] Recovery attempted by rudder neutralization.
[i] Recovery attempted by simultaneous movement of rudder to 5° with the spin and movement of ailerons to 2/3 (of 20°) with the spin.
[j] Recovery attempted by simultaneous movement of rudder 10° with the spin and movement of ailerons to 2/3 (of 20°) with the spin.
[k] Visual.
[l] Model entered an erect glide.
[m] Model recovered in an inverted dive.
[n] Model recovered in an erect glide.
[o] Recovery attempted by movement of rudder to 10° with the spin and movement of ailerons to full with the spin.

[redacted]

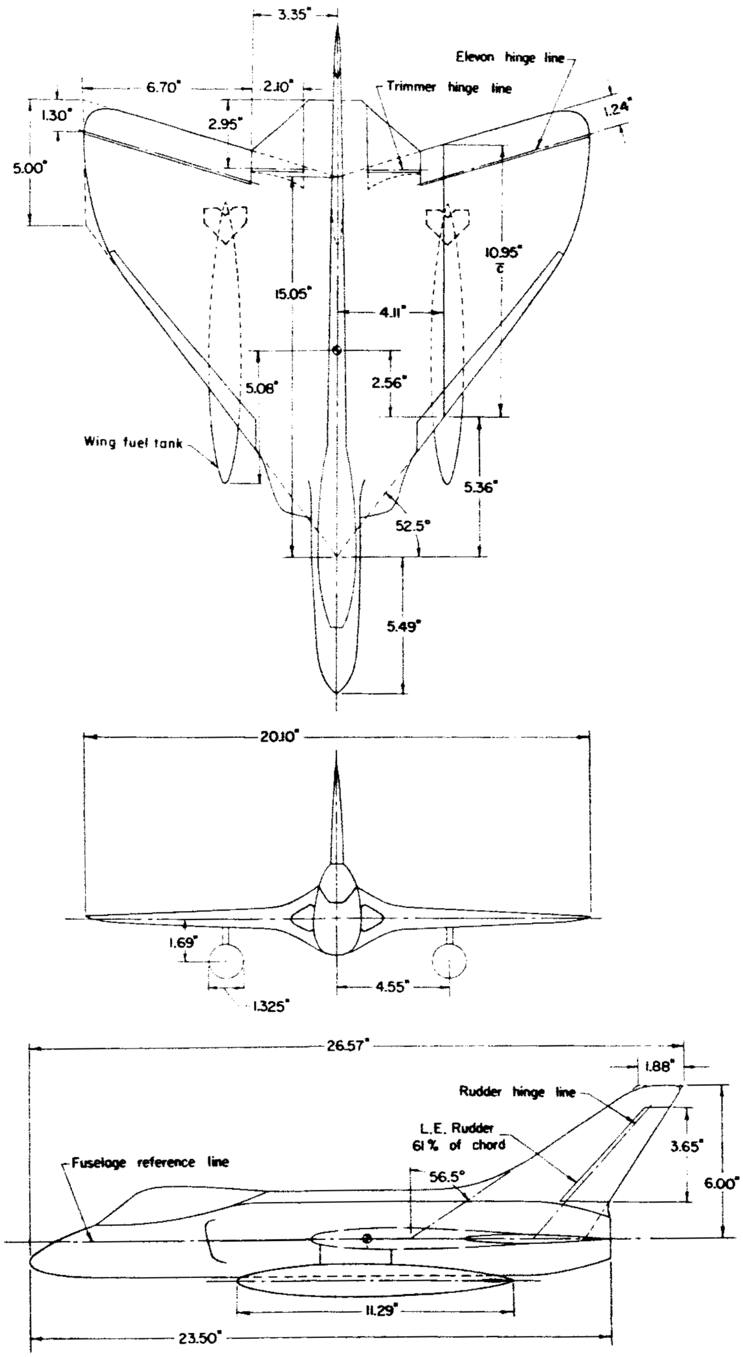



Figure 1.- Three-view drawing of the $\frac{1}{20}$-scale model of the Douglas XF4D-1 airplane as tested in the Langley 20-foot free spinning tunnel. Dimensions are model values. Center-of-gravity position shown is for the Design Flight loading.

[redacted]

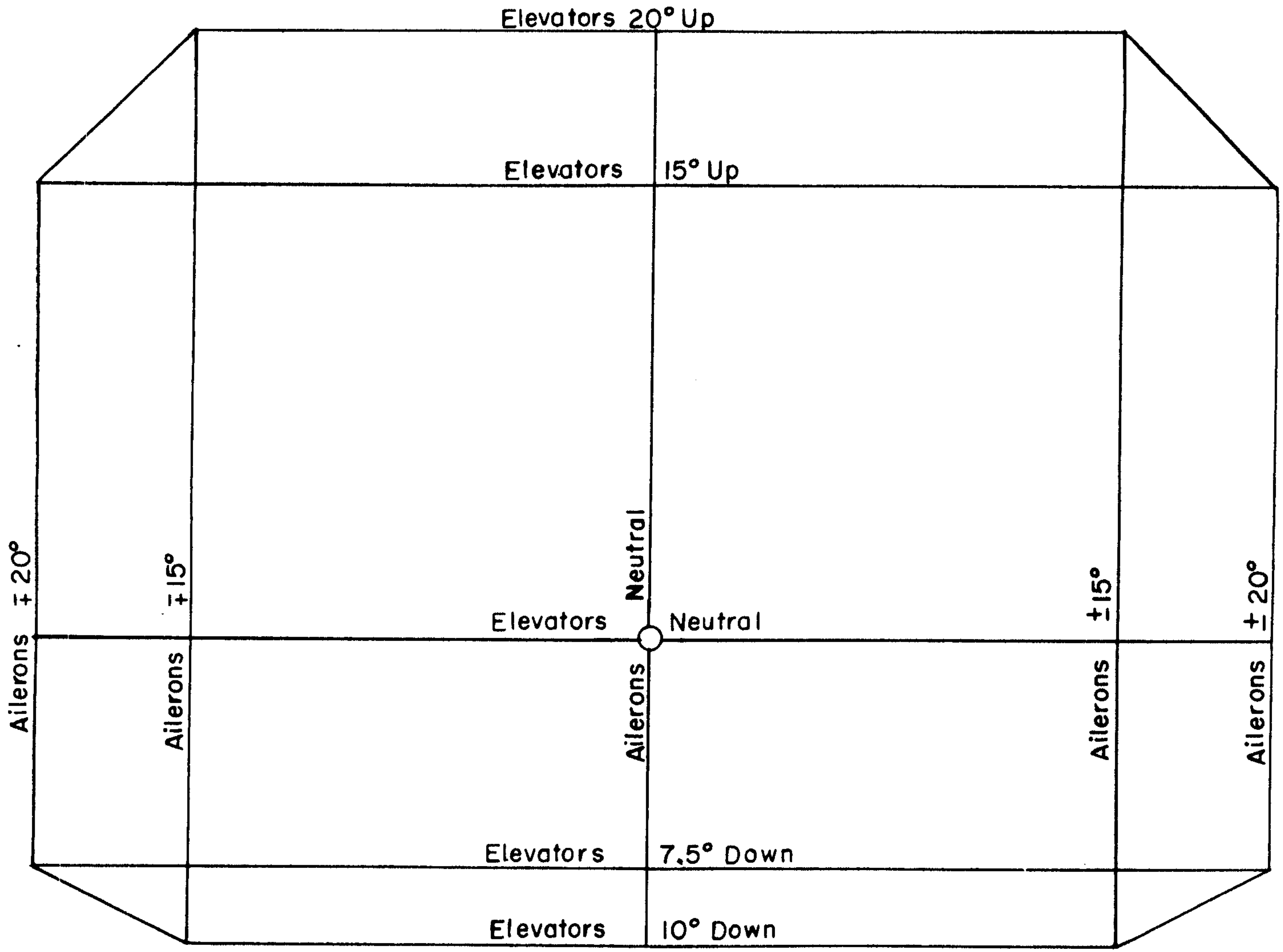



Figure 2.- Diagram showing maximum control deflections of the elevons in terms of elevators and ailerons for the Douglas F4D-1 airplane.

[redacted]

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TED NO. NACA AD 3116

By James S. Bowman, Jr.

## ABSTRACT

Model test results indicated that satisfactory recoveries from erect spins can be obtained by rudder reversal accompanied by movement of ailerons to full with the spin. To avoid entering another spin, all controls should be neutralized immediately after recovery. For satisfactory recoveries from inverted spins, movement of the rudder to at least neutral will be necessary and neutralization of all controls will be desirable.

## INDEX HEADINGS

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